

CPUC Covered Conductor Workshop

February 27, 2019

Overview & Objectives

- History & Evolution of Covered Conductor Design
- Testing and Analysis
 - Ignition & Electrocution Risk
 - Service Life & Durability
- Use by other Utilities
- Typical Construction Configurations
- Risk Analysis & Alternatives Comparison

A Brief History

- Covered Conductor has been used by utilities since the 1970s in Europe and the U.S.
 - Key driver: reliability improvement in dense vegetation areas, such as forests in Scandinavia, the U.K., New England, etc.
- Other drivers expand the use of covered conductors:
 - Tokyo, Japan: public safety in dense population
 - Southeast Asia (Thailand, Malaysia): animal protection (snakes, monkeys, rodents), and dense vegetation, also public safety in downtown Bangkok
- Reduction of “bushfires” has become a key driver for replacing bare with covered conductor in Australia
- Over the years, significant development in the covered conductor design led to improved performance and extended life

Nomenclature of Covered Conductor

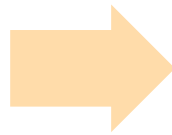
- Covered conductor: insulating materials, distinguished from bare conductor
- Covered conductor in the U.S.:
 - Covered conductor in lieu of “insulated conductor”, which is reserved for grounded overhead cable
 - Tree wire: widely used in the U.S. in 1970’s, typically one-layer covered, on cross-arm construction
 - Spacer cable: 2 or 3 layers of covering, support by messenger and trapezoidal insulated brackets
 - Aerial bundled cable (ABC): underground cable on poles with benefits of being grounded
- Covered conductor in the other parts in the world:
 - covered conductor, insulated conductor, coated conductor interchangeably
 - Scandinavia countries: SAX, PAS/BLX, BLX-T, typically installed in forests
 - Australia, Far East countries: CC/CCT; CCT with thicker insulation
- Covered Conductor at SCE:
 - Introduced standards in Q1, 2018
 - SCE has previous experience in aerial cable, and “tree wires”
 - Current SCE specification of covered conductor is more robust than CCT (e.g. better UV protection)

Evolution of Covered Conductor



Single Layer

- Protection on incidental contacts
- Less protection on long term contact with objects
- More susceptible to long term UV degradation (30+ years)



Two Layer

- Thicker overall insulation
- Improvement on insulation
- Tougher outer layer for abrasion protection
- Improvement on UV



Three Layer
(Current Standard)

- Capable of withstand long-term contact (semi-conductive shield)
- Higher conductor rating (cross-linking)
- Abrasion improvement
- Improved UV and tracking resistant (Titanium dioxide)

SCE Covered Conductor Design

- Three Layer Covered Conductor

- Conductor

- Aluminum Conductor Steel-Reinforced (ACSR)
 - Hard Drawn Copper (HDCU)

- Conductor Shield

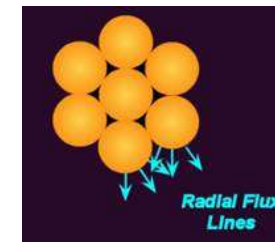
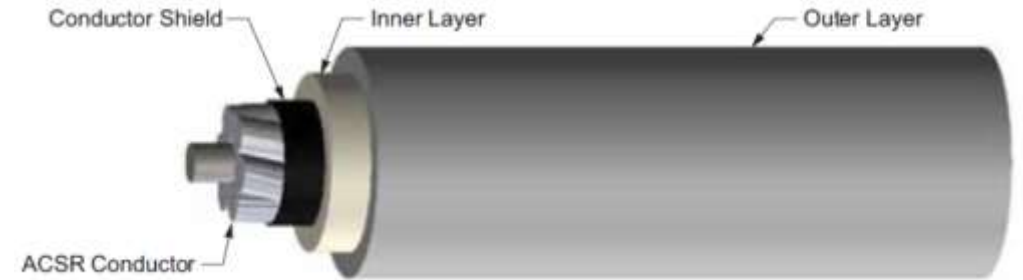
- Semiconducting Thermoset Polymer
 - Reduces stress, transforms strands into a single uniform cylinder
 - Extend service life of the covered conductor in case of contacts

- Inner Insulation Layer

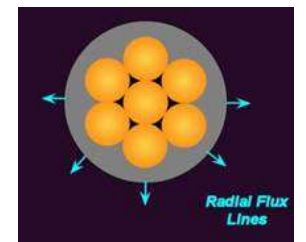
- Crosslinked Low Density Polyethylene: more flexible
 - High impulse strength: protect from phase-to-phase and phase-to-ground contact
 - Crosslinking: retain its strength and shape even when heated

- Outer Layer

- Crosslinked High Density Polyethylene: Abrasion and Impact Resistant; Stress-Crack Resistant
 - Titanium Dioxide: the most effective UV inhibitor, and providing the best track resistant



Flux lines without a conductor shield



Flux lines with a conductor shield

Covered Conductor Installation Options

Cross-arm Construction
(aka Tree Wire)



Most of SCE installations on Cross-arm
(SCE uses grey to reduce the impact of sun
light heating effect, thus increase ampacity)

Compact Construction
(aka Spacer Cable)



Some installations will be spacer cable
(e.g. replacement of tree attachments)

Computer Analysis Study Conclusion

- The analysis concluded that a foreign object contact with covered conductors will not cause a fault
- The results showed that covered conductors reduce the energy from tens of thousands of watts to well under one milliwatt
- This reduction prevents ignition (Australia studies: 0.5 Amps for less in 2 seconds would not ignite)

Simulation Method	Conductor Type	Current in Branch	Resistance of Branch	Power into Branch
PSCAD	Bare Conductor	2800 mA	5800 Ω	45,472 W
	Covered Conductor	0.18 mA	5800 Ω	0.00019 W
CDEGS	Bare Conductor	2730 mA	5800 Ω	43,227 W
	Covered Conductor	0.04 mA	5800 Ω	0.00001 W

Computer Analysis & Field Testing of Contact Cases

- Computer Analysis using electrical software (PSCAD, CDEGS) modeling contacts on conductors for fault current and energy
- Field testing was performed at SCE's EDEF Test Facility in Westminster to validate the computer model study
- Analysis and test cases:
 - Tree/Vegetation phase-to-phase contact
 - Conductor Slapping
 - Wildlife phase-to-phase contact
 - Metallic Balloon phase-to-phase contact

Tree Branch contact

- Energized at 12 kV
- Observations
 - No arcing
 - No damage to the covered conductor
 - No damage to the tree branch



Testing Other Contacts: No Arcing and Damage to Covered Conductors

Conductor Slapping



Simulating Animal



Mylar Balloon



Computer Analysis and Field Test Results

- Computer analysis and field testing validated that covered conductor will prevent faults and prevent ignition due to incidental contact

Simulated/Test Subject	Current		Energy	
	Simulation Current with Test Subject (mA)	Empirical Current with Test Subject (mA)	Power -Simulation (Watts)	Power – Empirical Testing (Watts)
Palm Frond	0.005	0.001	0.00525	0.00021
Brown Branch	0.006	-0.001	0.17	0.0048
Green Branch	0.003	0.001	0.000012	0.0000014
728 Ohm Resistor Ph-Ph	0.004	0.044	0.000000012	0.0000015
1024 Ohm Resistor Ph-Gnd	0.007	0.052	0.000000050	0.0000028
1024 Ohm Resistor Ph-Ph	0.005	0.03	0.0000000256	0.0000009216
Metallic Balloon	0.009	0.128	0.00000000030	0.000000066

- Computer and field test results showed contact current in the range milliamps. An Australian studies showed testing of 0.5 Amps or less in 2 seconds does not ignite

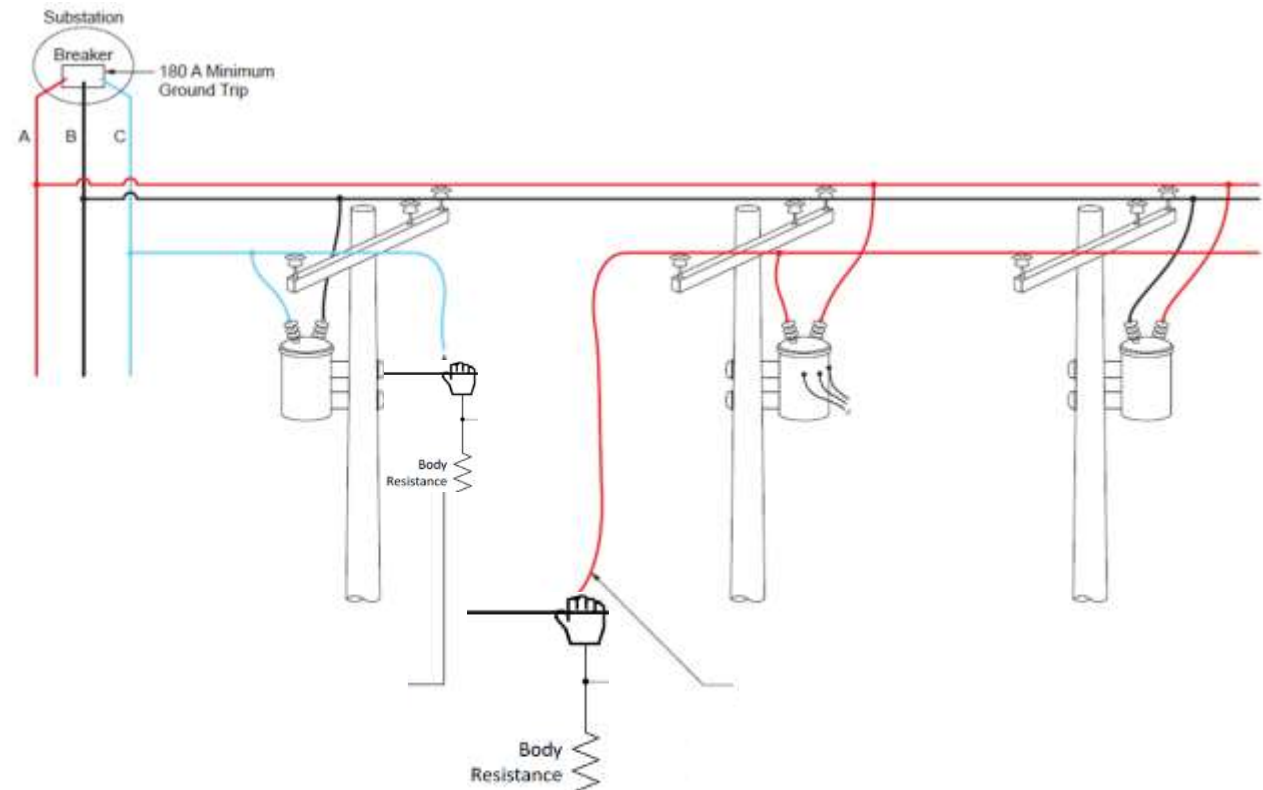
Understanding Wire Down

- Covered conductors should experience significantly fewer wire-down events compared to bare conductors
- Wire down risk comparison of bare vs. covered conductors
 - Bare conductor falling on the ground (intact or broken) poses risk of ignition and to public safety
 - Covered conductor falling on the ground (intact or broken) poses much less risk of ignition and to public safety
- Wire down detection
 - Traditional protection activates under high current (fault) vs normal current (load)
 - Wire-down fault current can often be low (called high impedance faults)
 - Typically occurs when wire lands on surfaces such as asphalt, concrete, sand, and dry soil
 - Traditional protection schemes have low probability of detecting high impedance faults
- Advanced Wire-down detection:
 - For this reason, the industry is investigating alternative protection schemes
 - For example, SCE implementing Meter Alarming Downed Energized Conductor (MADEC) system, which uses customer meter voltage and machine learning algorithms for detecting wire-down events

NEETRAC Testing – Energized Downed Conductor

- The following are test cases of energized wire down scenarios that were simulated and empirically tested by NEETRAC
 - Person holding broken **covered conductor** on **line side**
 - Person holding broken **covered conductor** on **load side**
 - Person holding broken **bare conductor** on **line side**
 - Person holding broken **bare conductor** on **load side**

*Note that bare conductor test cases were not performed in the laboratory.



NEETRAC Testing Summary

- Test Information:
 - Conductor: 1/0 Covered Conductor
 - Source: 12.447 kV
 - Test Results: Human contact current measured
- Conclusion:
 - Covered Conductor Touch Current: Generally Not Perceptible (below 1mA)
 - Overall, covered conductors can potentially provide public safety benefits during wire down events

	Covered Conductor		Bare Conductor
	Simulation Results (Theoretical Value)	Lab Test Results (Actual Values)	Simulation Results (Theoretical Value)
Line Side	0.220 mA	0.227 mA	5,300 mA
Load Side	0.218 mA	0.227 mA	34.2 mA

Effects of Electrical Current on the Human Body (Source: CDC)

Current	Effect
Below 1 mA	Generally not Perceptible
1 mA	Faint Tingle
5 mA	Slight Shock; Not painful but disturbing. Average individual can let go
6-25 mA (women) 9-30 mA (men)	Painful shock, loss of muscular control. The freezing current or "let-go" range. Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated
50-150 mA	Extreme pain, respiratory arrest (breathing stops), severe muscular contractions. Death is possible

Service Life for Covered Conductors

- Expected service life of **45 years** (equivalent to bare conductor)
 - Bare and covered conductor can operate and perform as designed past the 45 yrs
 - Beyond its service life, SCE believes the covering will continue to provide partial protection
- Factors supporting service life and performance:
 - Advancement of compound technology and upgrade of manufacturing equipment
 - Known service life of cross-linked polyethylene (XLPE) is 40 years minimum
 - Rigorous manufacturer qualification and production testing
 - Historical records with systems installed since 1951 are still in operation and performing as designed 67 years ago

Qualification & Production Testing: Ensure Long Service Life for Covered Conductor

- Qualification Testing per Insulated Cable Engineers Association (ICEA) S-121-733-2016 Standard, for examples:
 - Sunlight resistance (UV) testing (validates protection against sunlight, moisture, heat)
 - Track resistance testing (validates insulation performance in real life condition)
 - Maximum dielectric constant (ensures insulation strength of the covering)
- Routine production testing
 - DC resistance (validates electrical properties)
 - Unaged and aged tensile and elongation (ensure mechanical strength of the covering)
 - Hot Creep (validate cross-linking to thermoset materials)
 - Spark Test (validate no pinholes/faults on the insulation)
- Passing qualification and production tests ensures high quality of covered conductor and 45 years of operating life

Known Failure Modes

- Covered conductor could have burn down if not adequately designed or installed
- The following known issues are addressed either by design criteria or installation guideline
 - Electrical tracking on surface of covers
 - SCE's covered conductor design will include a track resistant XLPE outer layer. Additionally, SCE will mitigate tracking by using polymeric insulators, using crimped connectors, and using a low carbon content sheath.
 - Arc generated from lightning strikes
 - Surge arresters will be installed at all overhead equipment locations and at UG Dips.
 - Aeolian (Wind-Induced) Vibration
 - Sag and Tensions for the covered conductor will take into account the terrain. There will be two separate tables for light and heavy loading. The loading limits account for wind and ice.
 - Premature Insulation Breakdown
 - SCE's Covered Conductor design uses a Cross-linked High-Density Polyethylene layer to help resist abrasion. Additionally, covered conductor must be handled with care in order to prevent damage to the covering.
 - Discussion with other utilities indicated that older covered conductor design performed as intended even after 50 years

Benchmarking

- Global literature research: Europe, Asia, Australia, U.S.
- Surveying utilities: NEETRAC, WUC, First Quartile
- Benchmarking: KEPCO, Victorian utilities, Northeast utilities, United Power
- Some key takeaways:
 - Most utilities in the U.S. use bare conductors
 - Success stories on covered conductor preventing ignitions
 - Lessons learned of challenges and improvement
 - Collaboration helped SCE to prepare specification, standards and deployment faster

Round Table Benchmark with Northeast Utilities

- Conducted an in-person discussion on covered conductor experience with the Northeast utilities:
 - Hendrix (manufacturer), Liberty Utilities (New Hampshire), Groveland Light (Massachusetts), Holyoke (Massachusetts), Middleton (Massachusetts).
 - Past standards engineer of Eversource attended as well
- Covered Conductor Systems
 - New England overall is approximately 80% Covered Conductor and 20% Bare
- End of life
 - Covered conductor still looks and performs the same after 50+ years of service
- Issues
 - Manufacturing problems due to ring cuts was experienced in the late 70s before cleanrooms
 - Corona is main failure mode (phase to ground through tree), but it takes years to fail
 - None has experienced Aeolian vibration issues
 - None has encountered water ingress
- Lightning
 - Burn down happens at stripped portion
 - Add lightning arrestors at equipment, transitions to bare, and dead-ends
 - Had enough incidents to decide to install lightning arresters at end of line
 - All advise not to install lightning arresters at every 1000 ft. Avoid stripping as much as possible.

Ausnet – Covered Conductor Ignition Mitigation

- A cypress tree blew onto covered conductor during a storm in December 2015
- Ausnet personnel responded three days after the storm and found the tree on conductors
- No broken conductor, no service interruption, no ignition.
- The spacers were knocked off and the conductors wrapped up.
- Insulation thickness design on each covered conductor prevented a phase-to-phase fault.
- power shutdown to unwrap the conductors and reinstall the spacers.



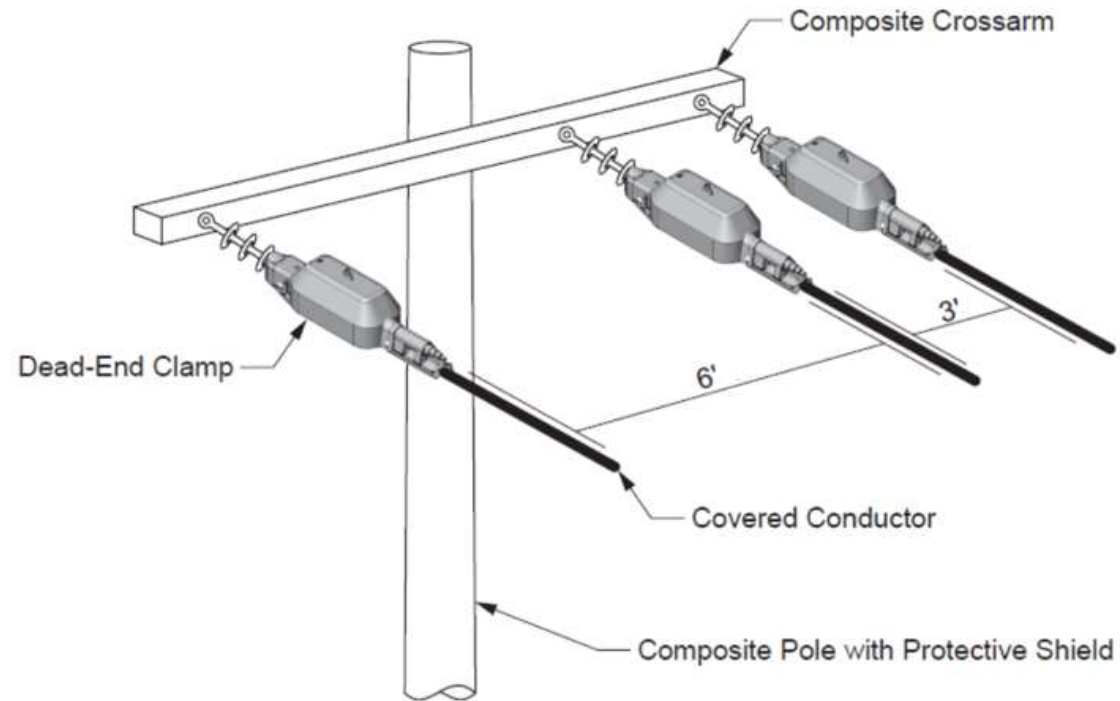
An United Power Experience

- We also learned some success stories of covered conductor that prevented wildfire ignitions from United Power in Colorado
- United Power has experienced wildfires in years past in the forested area, typically in high elevation of Colorado.
- To mitigate this issue, United Power installed covered conductor on spacer configuration due to compact right-of-way.
- United Power received a notification from the forest services tree fall on line after a wind storm on Fall 2018
- United responded to the site and removed the tree, found the covered conductor intact, with no interruption or wildfire ignition.
- The manager at United Power reflected that this wind storm event would have resulted in a wire down event, and possibly a wildfire ignition if the tree fell on bare conductor span.

Three-wire Dead-end Construction

Introduce new standards for dead-end cover, composite pole and cross-arm

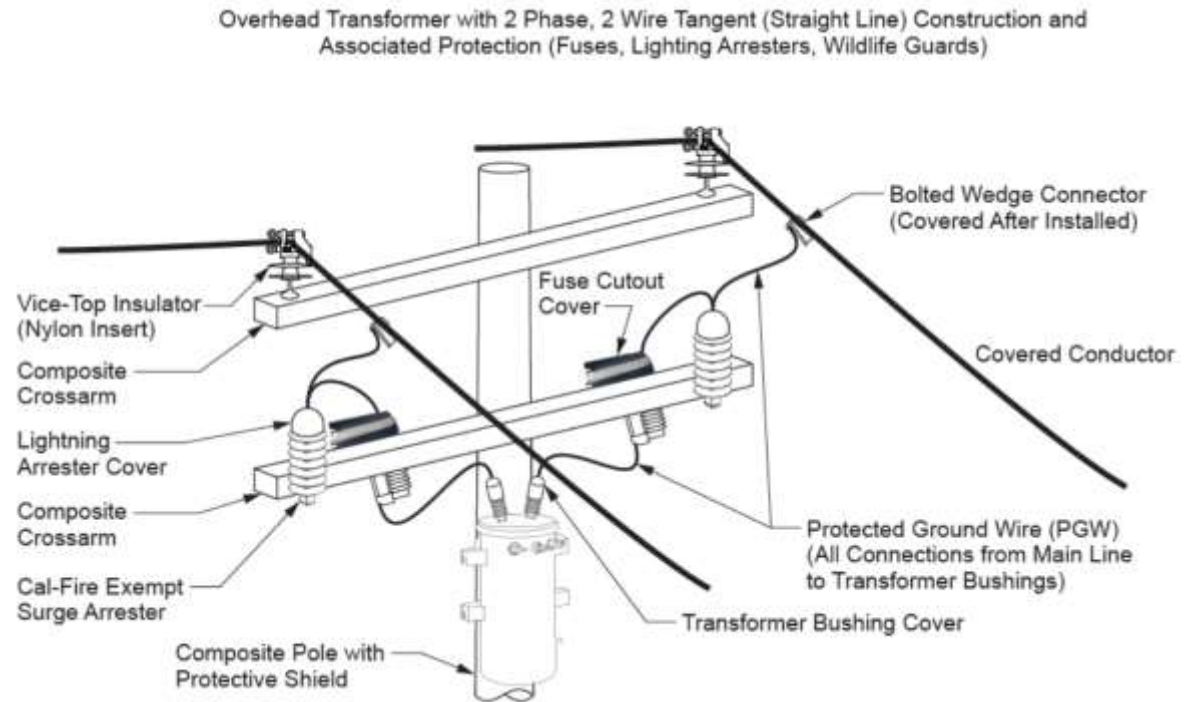
- Covered Conductors need to be stripped at the dead-end
- Use Dead-end Covers to protect exposed areas



Same concept for four-wire and two-wire constructions

Tangent 2 Wire with Transformer Construction

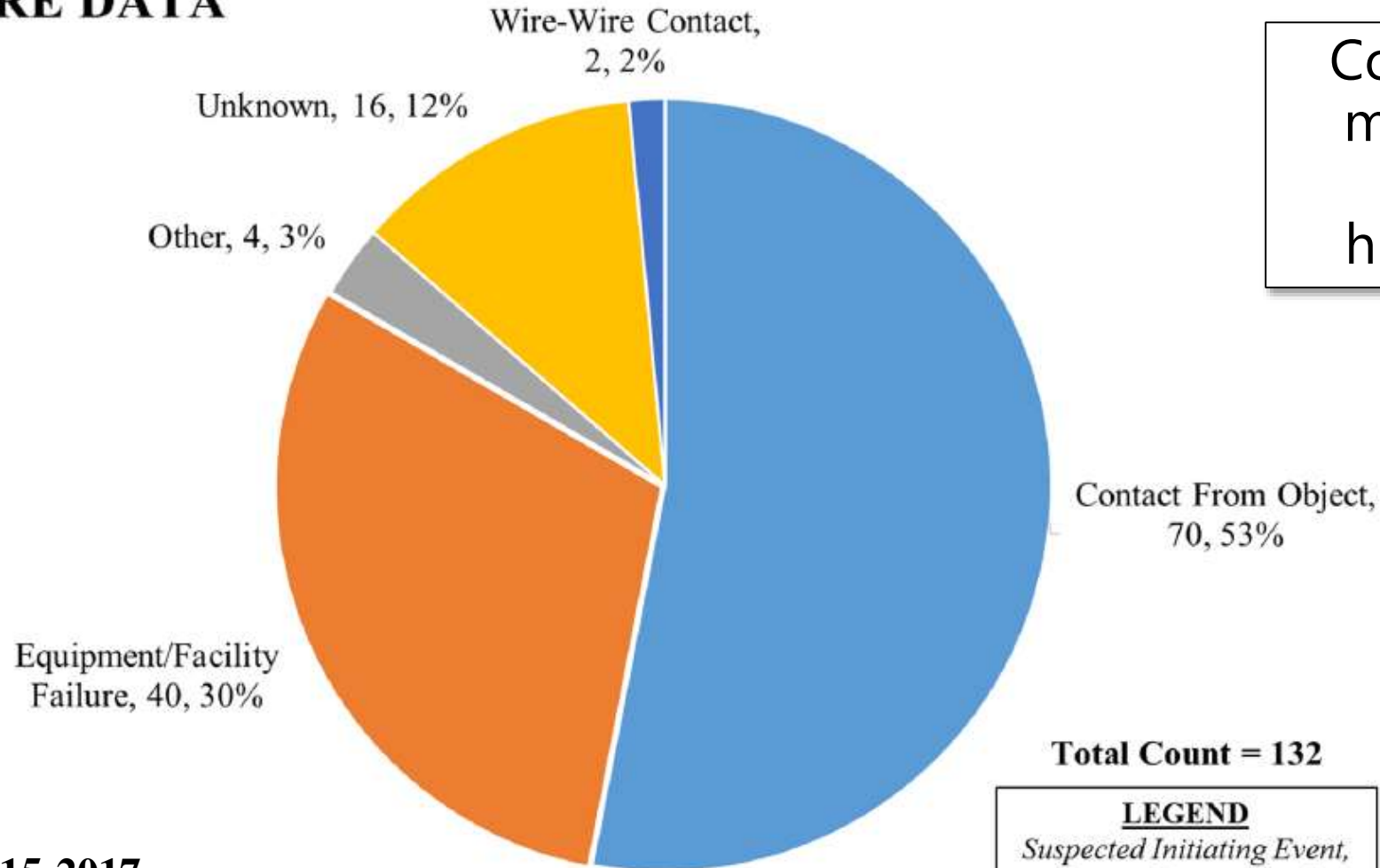
- **Use Surge Arresters at all Overhead Equipment**
 - Treat Covered Conductor systems like high lightning area
 - Covering prevents the arc from moving
- **Use Bolted Wedge Connector**
 - Cover after installation
- **Use Protected Ground Wire**
 - Connections to equipment will be covered
- **Wildlife protection on equipment**
 - Cover Lightning Arrester, Transformer Bushing, and Fuse



Same concept for connecting to other equipment: capacitor, switch, remote automatic recloser, etc.

SCE Historical Fire Causes

FIRE DATA



Covered Conductor mitigates ~60% of drivers causing historical ignitions

Total Count = 132

LEGEND

*Suspected Initiating Event,
Count, Percent Total*

2015-2017

Distribution Voltage Infrastructure in HFRAs

Alternatives Considered

- Wildfire Mitigation Options
 - Covered Conductor
 - Replace existing conductor with new, appropriately sized, covered conductor
 - Bare Conductor
 - Replace existing conductor with new, appropriately sized, bare conductor
 - Underground Relocation
 - Relocate existing overhead primary voltages to underground
- See SCE's GSRP and RAMP filings for additional details

Alternatives Mitigation Effectiveness Analysis

	ODRM Cause Code	Covered Conductor Effective?	Bare Conductor Effective?	Undergrounding Effective?
Contact From Object	Animal	Yes	No	Yes
	Balloon	Yes	No	Yes
	Other	Partial (Yes for 'Foreign Material')	No	Yes
	Vegetation Blown; Vegetation Overgrown	Yes	No	Yes
	Vehicle Hit	No	No	Yes
Equipment / Facility Failure	Transformer	No	No	Yes
	Conductor / Wire	Yes	Yes	Yes
	Splice / Connector / Tap	Yes	Yes	Yes
	Fuse / BLF / Cutout	No	No	Yes
	Lightning Arrestor	No	No	Yes
	Crossarm	No	No	Yes
	Pothead	No	No	Yes
	Insulator	No	No	Yes
	Switch / Disconnect AR	No	No	Yes

Comparison of Alternatives

- Covered Conductor has the greatest mitigation effectiveness per dollar spent and is 85% less than the cost of Underground Relocation

Alternative	Drivers Mitigated	Cost per Mile (\$ million)	GSRP Mitigation Cost Ratio
Covered Conductor	60%	0.43	1.40
Bare Conductor	15%	0.30	0.50
Underground Relocation	100%	3.0	0.33

- SCE's RAMP analysis shows covered conductor has the greatest risk-spend efficiency (RSE)
 - ~**3.4x** greater than Bare Conductor
 - ~**4x** greater than Underground Relocation
- Speed of Covered Conductor deployment is much faster than Underground Relocation